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The conservation history of Arabian gazelles (*Gazella arabica*) in Israel — do fifty-five years monitoring help to define future incentives

Benny Shalmon[1]; Torsten Wronski[2]*

[1]Israel Nature and Parks Authority (INPA), Southern District, Eilat, Israel (former address) and 643 Marva Lane, Eilat, Israel.

[2]School of Biological and Environmental Sciences, Liverpool John Moores University, Byrom Street, Liverpool, L3 3AF, UK.

Corresponding Author: Torsten Wronski

School of Biological and Environmental Sciences, Liverpool John Moores University, Byrom Street, Liverpool, L3 3AF, UK.

Email: t_wronski@gmx.de

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Abstract

We aimed to review the population development and conservation history of Arabian gazelles *(Gazella arabica acaciae)* in Israel, to summarise conservation-related research and to provide future recommendations.

1. We researched published online material as well as files and archives of the Israel Nature and Park Authority, compiling old documents, field notes, numerous unpublished reports and photographs.

2. The population development-since monitoring started in 1964 is viewed in a historical context. The conservation history was critically revised and screened for the most eminent threats, including low fawn survival, high predation pressure, low genetic diversity (inbreeding), competition with dorcas gazelles (*Gazella dorcas*) and climate change.

3. We describe what conservation actions were implemented over a period of 30 years, the success and drawbacks of these measures, and what research projects were carried out to facilitate conservation.

4. Based on those results, we aimed to give future recommendations, delineating scenarios that might be useful to reverse the population decline, such as captive breeding and translocations, out-breeding, irrigation, water and food supply, predator control through fencing or culling and parasite surveillance.

5. Finally, we discussed the proposed capitulation, allowing the population to go extinct in the face of further emerging threats like climate change or disease outbreaks. We emphasise the importance of this population for the survival of the species in general, but also for the functional diversity of the hyper-arid desert ecosystem in the southern Negev.

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Introduction

Historically, the Arabian gazelle (*Gazella arabica*) occurred along the peripheries of the Arabian Peninsula, reaching from the Arava Valley in southern Israel, along the Hejaz and Asir Mountains in western Saudi Arabia into Yemen and Oman, and further north into the United Arab Emirates (UAE; [1]). Throughout their natural range, Arabian gazelles experienced dramatic population declines in recent decades (Israel: [2,3]; Saudi Arabia: [4-7]; Yemen: [8]; Oman: [9-11]; UAE: [12]), and currently the IUCN Red List classifies the species as 'vulnerable' (C2a,i) with less than 7,000 individuals persisting in the wild [13]. To date, the largest population of G. arabica survives on the Farasan Islands in the southern Red Sea (ca. 1,000 individuals: [14,15]).

Until recently, the Arabian gazelle and its sister taxon, the mountain gazelles (*Gazella gazella*) from the Mediterranean Levant were merged in one species [16-18]. Based on phenotypic differences in fur colouration, horn shape, and skull morphology, [19] divided the taxon into at least three species and seven subspecies. More recent morphometric and phylogenetic analysis suggested a division into two species, i.e. G. arabica and G. gazella, with little or no intra-specific, genetic variation [20-23]. One of the seven subspecies mentioned by [19] was described as G. gazella acaciae (now G. arabica acaciae) from the Arava Valley in southern Israel [24]. At least since the British mandate for Palestine in 1920, this population was isolated from Arabian gazelles on the Arabian Peninsula [25]. In their phylogenetic analysis, [3] proposed that the Arava population of G. arabica formed a distinct group, closely related to gazelles from the Farasan Islands. This interesting observation suggests that Farasan gazelles originated in Palestine (or Sinai), before translocated to the archipelago by ancient traders or seamen as a self-sustaining source of fresh meat [26,27]. To date, G. arabica acaciae represents the only Arabian gazelle population outside the Arabian Peninsula, and probably the only one that does not suffer from illegal offtakes through hunting or live capture [27,28].

Since the discovery of G. arabica in Israel, the species has received a considerable conservation input but unfortunately with limited success. In our current article, we want to revise and reflect on the conservation and monitoring efforts hitherto devoted to the G. arabica population in Israel, leading into a discussion on how to advance the populations' management in the future. Overall, we want to highlight the importance of this population for the survival of the species in general, i.e. by facilitating high levels of intra-specific heterogeneity within the species, but also its importance for biodiversity conservation in Israel. Initially, we outline the conservation history of Arabian gazelles in Israel by describing the population development since the British mandate for Palestine. Second, we describe what conservation actions were implemented over this period, the success and drawbacks of these measures, and what research projects were carried out to facilitate conservation. Subsequently, we describe the current conservation status of the population and elaborate on most recent research initiatives, aimed to determine why the situation has not improved despite 30 years of sustained conservation efforts. Based on those results, we aim to give a future perspective, delineating scenarios that might be useful to reverse the decline, including captive breeding, out-breeding, translocations, and predator control. Finally, we discuss a proposed capitulation, i.e. allowing the population to go extinct in the face of further emerging threats like climate change or disease outbreaks, additional to the various threats delineated in this review.

Methods

This review article intends to gather most (if not all) published and unpublished literature respective to the *Gazella Arabica* population in Israel and places it into a historical context. To accomplish this, we applied several search strategies such as computer-based search in 'Google Scholar', applying a selection of key words relating to the species, its ecology, distribution and conservation. The literature search was also extended to other countries in which the species occurs. Most important, we researched files and archives of the Israel Nature and Park Authority (INPA) and compiled old documents, such as field notes from the 1960s, numerous unpublished reports, mainly produced by the first author and David Blank, as well as images taken during their employment at the INPA. The review also includes a few unpublished data collected during the survey period, which extended over 55 years from 1965 to 2020.

Population development

At the prehistoric excavation sites of the Negev Desert, Arabian gazelles occurred as early as the Epipalaeolithic (late Pleistocene: 0.20 to 0.10 MYA; [29-33], an era with considerably higher precipitation and lower temperatures than today. At the time these studies were published, prehistoric records of gazelles from the Negev (other than dorcas gazelles, G. dorcas) were referred to G. gazella, assuming that a cooler and more humid climate during the Pleistocene allowed the species to extent further south than today (i.e. into the Negev and the Sinai Peninsula). Currently, it rather appears that the common ancestor of both species immigrated from Africa into the Middle East during the middle Pleistocene (1.73 to 0.86 MYA) and split into a humid-adapted form (G. gazella) and a dry-adapted form (G. arabica) separated by the 500 mm-isohyet [23]. Reports of gazelles from the Sinai Peninsula (Wadi el Arish; [34-36] thus likely refer to the dry-adapted form, rather than to G. gazella.

The first reference to G. arabica in Israel originates from the Game Conservation Proclamation issued by the British mandatory government in March 1924 [25]. Interestingly, the proclamation mentioned three species of gazelles, i.e. G. merrili (a synonym of G. gazella), G. dorcas and G. arabica. However, the law was not enforced and between 1930 and 1945 large numbers of gazelles were shot by Transjordan Frontier Corps and police forces in the southern Negev. In the 1970s Heinrich Mendessohn was the first to document the status of Israeli gazelles, revealing about 300 Arabian gazelles to occur in the Arava Valley. This population was scattered into two large (and several small) sub-populations, one as far north as Hazeva with about 200 individuals, the second in the south between Eilat and Yotvata with 60-70 individuals [25,37] (Figure 1). At that time, a few individuals were occasionally observed in the wadis and mountain plateaus west of the Arava Valley (Biqat Uvda, Nahal Zihor, Nahal Milchan, Moon Valley; [38] (Figure 1). Although hunting wildlife was prohibited in Israel since 1955 [39], the northern population was eradicated between 1956 and 1963 due to illegal hunting by soldiers of the Israeli Defence Forces [25,40]. However, the southern population persisted and by the time it was first counted by Giora Ilani in 1964, only 42 individuals persisted [41]. Subsequently, the southern population, together with resident dorcas gazelles were counted annually (Ilani unpubl. data), experiencing a first all-time low in 1974, with only 17 individuals surviving in an area that was confined to the Arava Valley between Eilat in the south and Yotvata in the north (Figure 1,2). This population consisted of two groups, one between Eilat and Timna (near Beer Ora), the second in the preferred Vachellia (formerly Acacia) habitat between Timna and Yotvata. By 1983 the southern group had vanished while the northern group declined to a second all-time low in 1981 of only 16 individuals in an area not more than 6 km^2 [42,43] (Figure 2). During the 1980s the population recovered, gaining its maximum in 1988 with 53 individuals [38,44-46]. Subsequently, the number declined again throughout the early 1990s, reaching a third all-time low in 1996 with a shocking overall population size of only 10 individuals-the lowest value ever recorded [47,48] (Figure 2). From 1996 to 2010 the population remained stable at a very low level (11-24 individuals), with low recruitment and high losses due to road kills and predation [49,50]. In 2005 the INPA decided to protect the remaining animals by fencing a 3.5 km^2 enclosure within the Yotvata NR. Before the enclosure was completed in July 2006, the number of gazelles decreased to another all-time low of merely 11 individuals by the end of 2005 [2] (Figure 2). Contrary to Blank's [2] expectations, the G. arabica population sharply increased after the fence was completed reaching 55 individuals in 2012 [27]. Due to three consecutive flash floods and the subsequent collapse of the fence in winter 2012/13, wolves entered the enclosure, decimating the number of Arabian gazelles again to 12 individuals [3,28] (Figure 2). After the fence was repaired in June 2013, the population recovered, reaching 32 individuals in 2019 [28]. Most recently (May 2020), wolves managed to enter the enclosure again, killing 9 gazelles (7 females, 2 fawns) in a few nights, declining the population to 23 individuals. Looking at the sequence of population change from 1964 to 2020 (Figure 2), the population has experienced strong periodic undulations and never exceeded 70 individuals. The overall trend points downwards, suggesting that in the long-term the population will most probably face extinction.

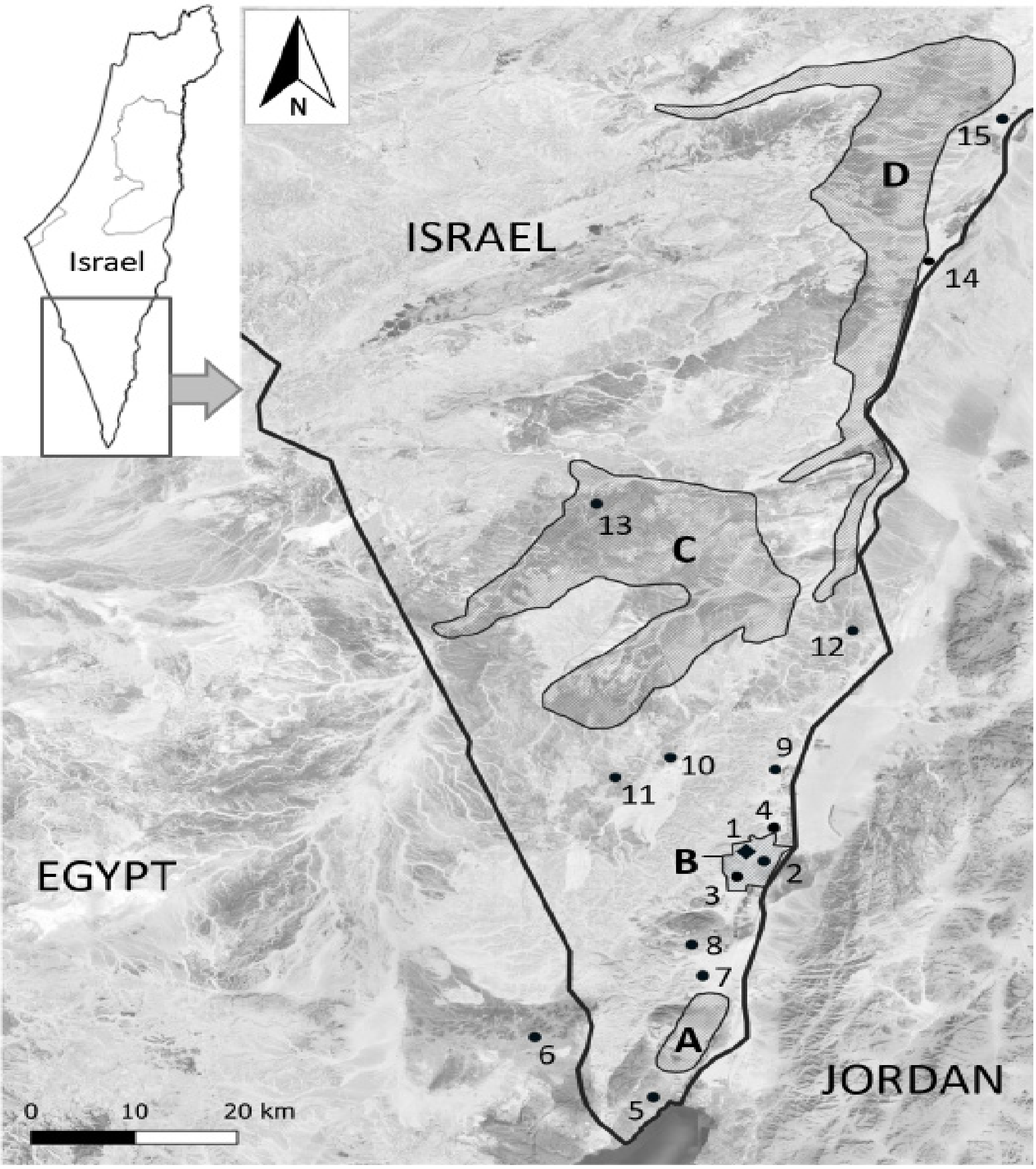

Figure 1: Southern Negev desert including settlements, locations from which Arabian gazelles (Gazella arabica) were currently or previously reported (1-14) and areas into which they could be reintroduced (A-D; Table 5): 1) Gazella arabica enclosure within the Yotvata Nature Reserve, 2) Hai-Bar Wildlife Reserve within the Yotvata NR, 3) Kibbutz Samar, 4) Kibbutz Yotvata, 5) Eilat, 6) Moon Valley, 7) Beer Ora, 8) Timna, 9) Ketura, 10) Biqat Uvda, 11) Nahal (Wadi) Milchan, 12) Nahal (Wadi) Shita, 13) Nahal (Wadi) Zihor, 14) Shezaf NR, 15) Hazeva. A) Evrona NR and Eilat Mountains NR, B) Yotvata NR, C) Hanhalim Hagdolim NR and Kezev-Hayun NR, D) Eastern Mazok Hazinim NR and Machteshim-En Yahav NR.

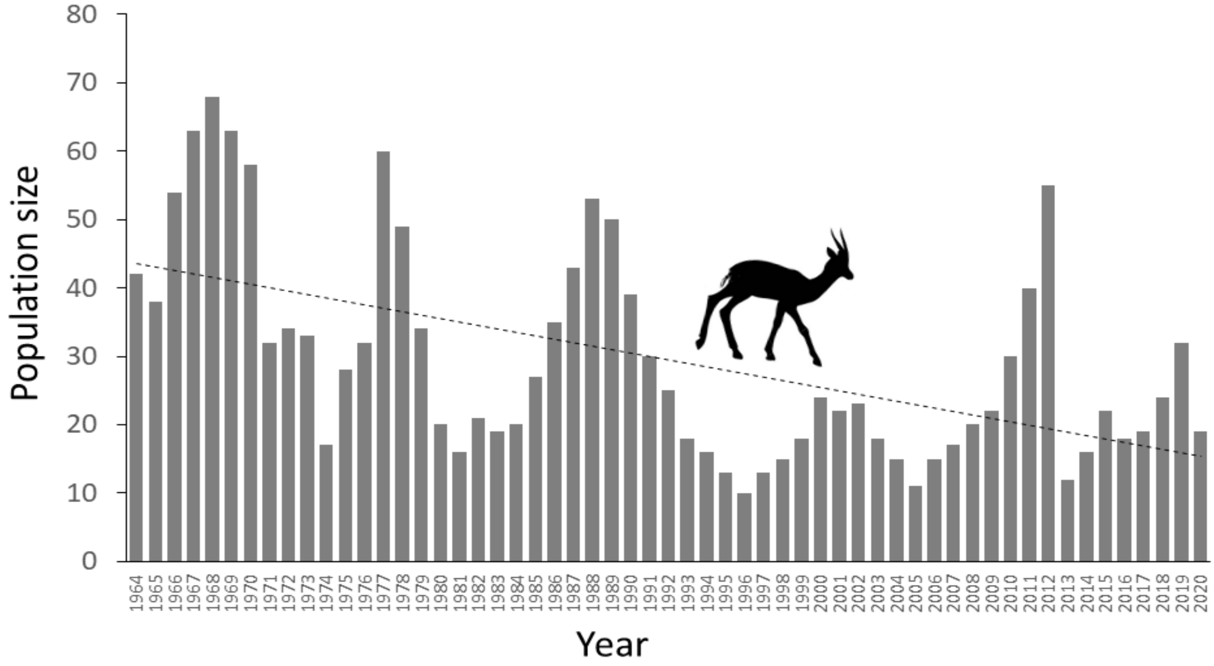

Figure 2: Population size development of Arabian gazelles (*Gazella arabica*) in the southern Negev Desert from 1964 to 2020. Although regular undulations are prevalent, the overall trend is decreasing (dotted line).

Conservation and research history

Through millennia of mass-killing using desert kites [51,52], gazelle numbers in the Middle East declined, but not to the degree that species were driven to extinction [53]. The existence of gazelles was jeopardised after World War One, when automatic firearms and motorised vehicles became widely available to local communities [25,54,55]. Moreover, an ever-increasing human population created a growing demand for crops and thus for cultivable acreage. No permanent settlement existed in the Arava Valley until the foundation of more than 20 agricultural settlements and the city of Eilat in the 1950s. This and the construction of the Eilat highway triggered an uncontrolled loss of natural habitat, supposedly contributing to the decline of Arabian gazelles in the 1970s [25] (Figure 2). Settlements and agriculture led to increased water consumption, lowering the ground-water table in the southern Arava Valley by 13 m and drying-up springs, salt marshes and the preferred gazelle habitat of the Vachellia groves [37]. Vachellia-dominated habitats were already proposed by [56] to be the most preferred habitat of Arabian gazelles and initial research on the Arava population confirmed this preference [24,43]. Consequently, in 1970 the Vachellia-dominated areas near the settlement of Yotvata were gazetted as the Yotvata Nature Reserve.

Shalmon [43,44] was the first to carry out research in the newly protected area, reporting on the behavioural ecology of Arabian gazelles in Israel. A study on the dietary preferences revealed that the food comprises 61% to 87% Vachellia tortilis and V. raddiana leaves, pods, flowers and resin (Figure 3-5). Like Arabian gazelles from the Arabian Peninsula [36,61], fawns are born throughout the year with a strong breeding peak in spring and a smaller one in autumn. Year-round, adult males (Figure 6A, B) occupy small permanent territories of 0.3 to 0.6 km^2, while females live in matrilineal groups with a mother and her last (and often second last) born daughters. (Figure 6C). In this context two behaviours previously not described for Arabian gazelles were observed, i.e. the formation of crèche groups (aggregations of similar-aged fawns often accompanied by a female guard; Figure 6D) and the association with cape hares (Lepus capensis; Figure 7). Other behaviours previously described for Arabian gazelles [61] were verified and documented during this period, including the performance of various anti-predator behaviours (i.e. stotting and predator mobbing, lying-out of fawns, maternal removal and consumption of urine and feces; Figure 8A-F,9D) as well as play behaviour (e.g. purposelessly jumping into the air, lifting all four feet off the ground simultaneously; Figure 10A, B). Shalmon [43] also proposed that browsing on hind legs (Figure 11A,B) is a strategy to avoid competition with sympatric dorcas gazelles (Figure 11C) which hardly perform this behaviour and thus have a much lower browse line [66]. Beside competition, [67] anticipated predation by wolves to be the main reason for the decline of the population. However, scat analysis revealed that only 14% of the diet was indigenous prey (including gazelles) but around 50% were human subsidies such as agricultural produce or garbage [67] (Figure 11D).

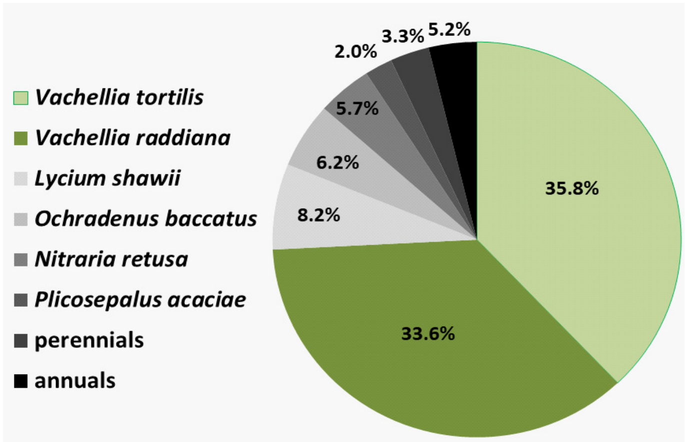

Figure 3: Percentage feeding time spent on food plants preferred by G. arabica in the Yotvata NR. Note that Vachellia leaves, flowers and pods are rich in energy, protein and water compared to other plants [57]. Vachellia raddiana and V. tortilis are evergreen and have different flowering and fruiting regimes: V. raddiana trees flower from June to December and produce ripe pods in the subsequent summer (June-July), while V. tortilis trees flower from May-July and produce ripe pods from August to September of the same year [58,59].

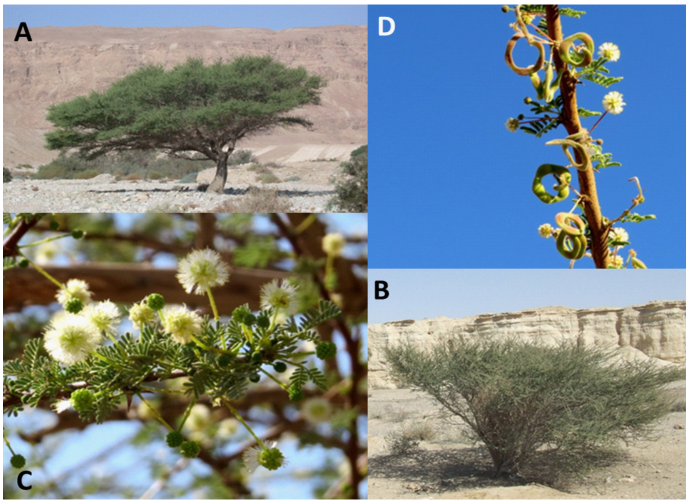

Figure 4: In summer and autumn (April to October) Arabian gazelles in Israel depend mainly on Vachellia trees, i.e. the leaves of V. raddiana **(A)** and Vachellia tortilis **(B)**. Moreover, a large proportion of the gazelle's diet at this time consists also of flowers and pods of both Vachellia species (**C**: V. raddiana, **D**: Vachellia tortilis). In winter and spring (December to March) however, gazelles feed more on other plant species such as shrubs and annuals (see Figure 3).

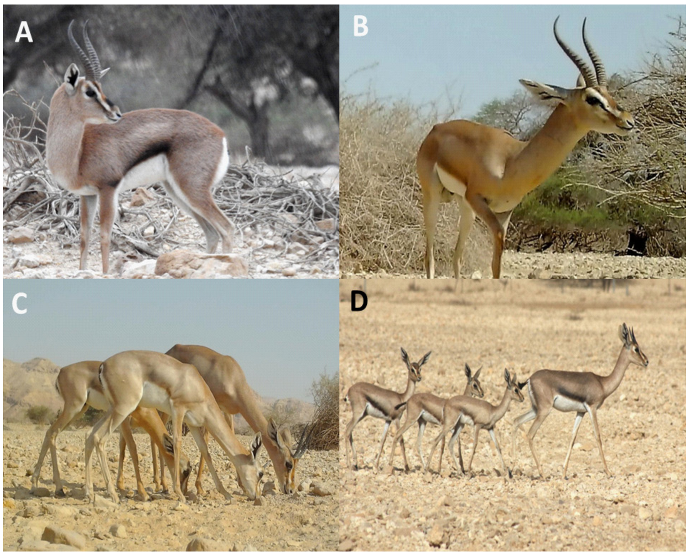

Figure 6: Whether in winter **(A)** or summer **(B)**, male Arabian gazelles (*Gazella arabica*) occupy and defend territories, while females live in matrilineal groups with a mother and her last (and often second last) born daughters **(C)** A behaviour previously not described for Arabian gazelles is the formation of crèche groups, i.e. the aggregations of similar-aged fawns often accompanied by a female guard **(D)** This phenomenon was observed in 2012 and 2020 when the population size was larger than 50 individuals.

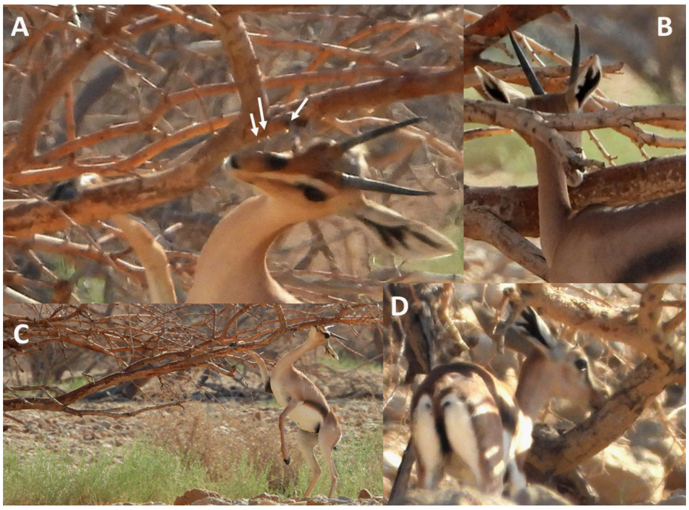

Figure 5: Female (**A,B,C**) and juvenile Arabian gazelles (**D**) browsing on resin secreted from a dead branch of Vachellia raddiana in the Yotvata NR, Israel. Arrows in A) notify resin drops. Resin is a combination of composite polysaccharide and as such difficult to digest by mammalian enzymes. Digestion can only be facilitated by fermentation of gut microbes. It contains only small amounts of proteins, no lipids, and low levels of vitamins. Moreover, resin is difficult to obtain, limited in quantity, and primarily a source of energy or minerals. Some studies have highlighted the potential to increase the resistance against pathogenic bacteria or as a general antimicrobial to prevent fungal or helminth infections [60].

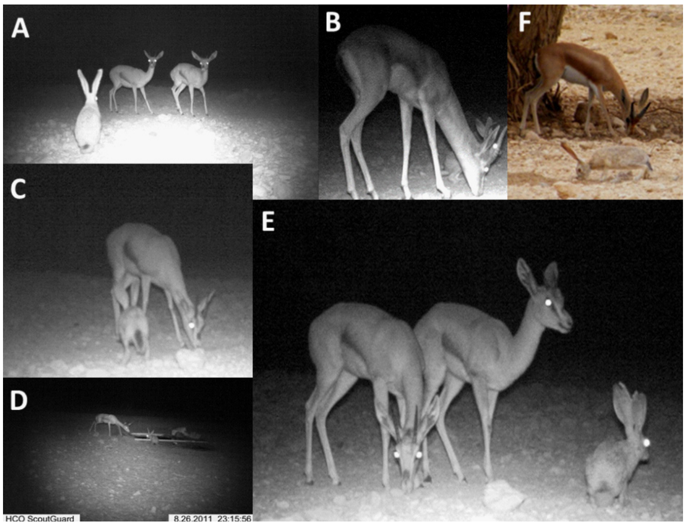

Figure 7: From November 2007 to May 2020, camera traps were positioned at water troughs and feeding stations, established to supply gazelles with additional water and protein rich food pellets. Preliminary analysis revealed that cape hares (Lepus capensis) seem to seek the vicinity of gazelles since about 35% (30) of all images containing a hare (87) also pictured a gazelle. By contrast, only 31, out of hundreds of gazelle pictures contained a hare. Almost all camera trapping images of gazelles associated with cape hares were taken at night **(A-E)**, only in one case, a hare joining a gazelle was capture during the day **(F)**.

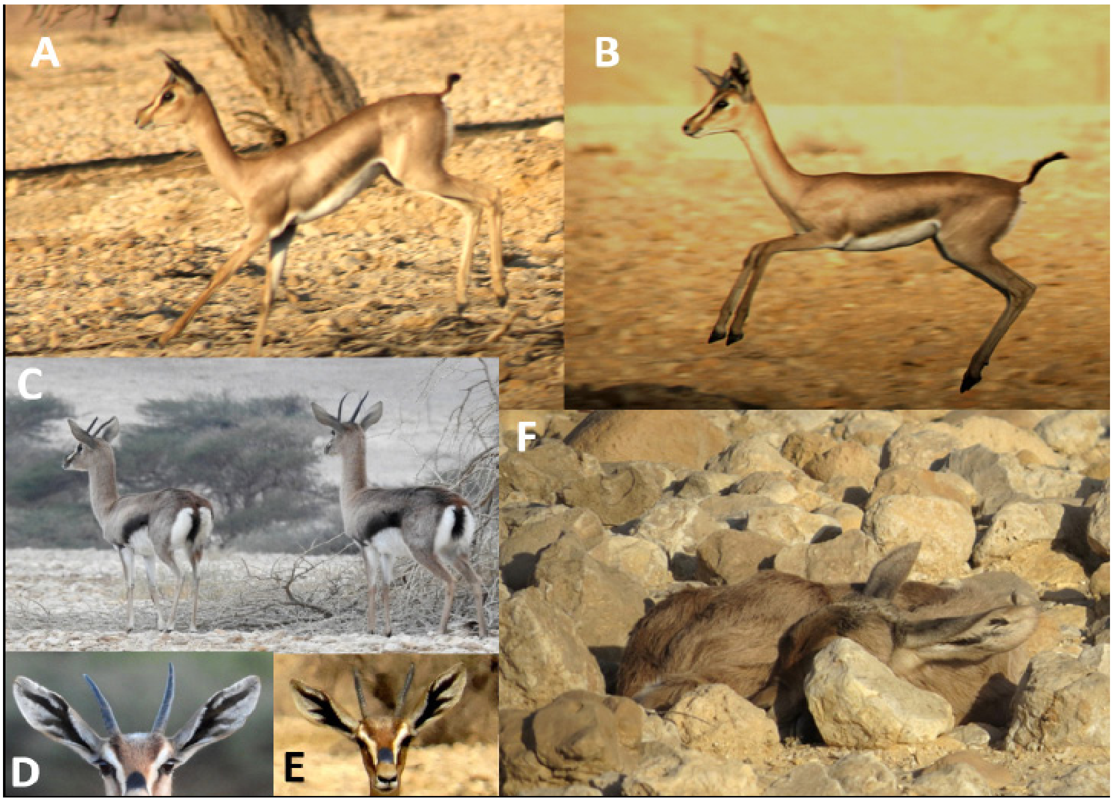

Figure 8: Behaviours previously described for Arabian gazelles [61] were verified and documented during this study, including stotting [62], a performance interpreted as an honest signal to predators, indicating that the performing individual would be difficult to catch **(A,B)**. Signalling behaviours were suggested to have evolved because they modify the behaviour of the receiver (predator) to the benefit of the signaller (prey; [63]). Following this idea, we propose that directing the ears, and the flamboyant inner pattern, towards a predator could be interpreted as an honest signal by the gazelles, indicating the predator that it was detected and an assault will be therefore futile **(C,D,E)**. Lying-out behaviour is performed by young fawns during the initial period when they rest quietly in self-chosen hides such as among rocks, under shrubs or in the shade of a tree **(F)**.

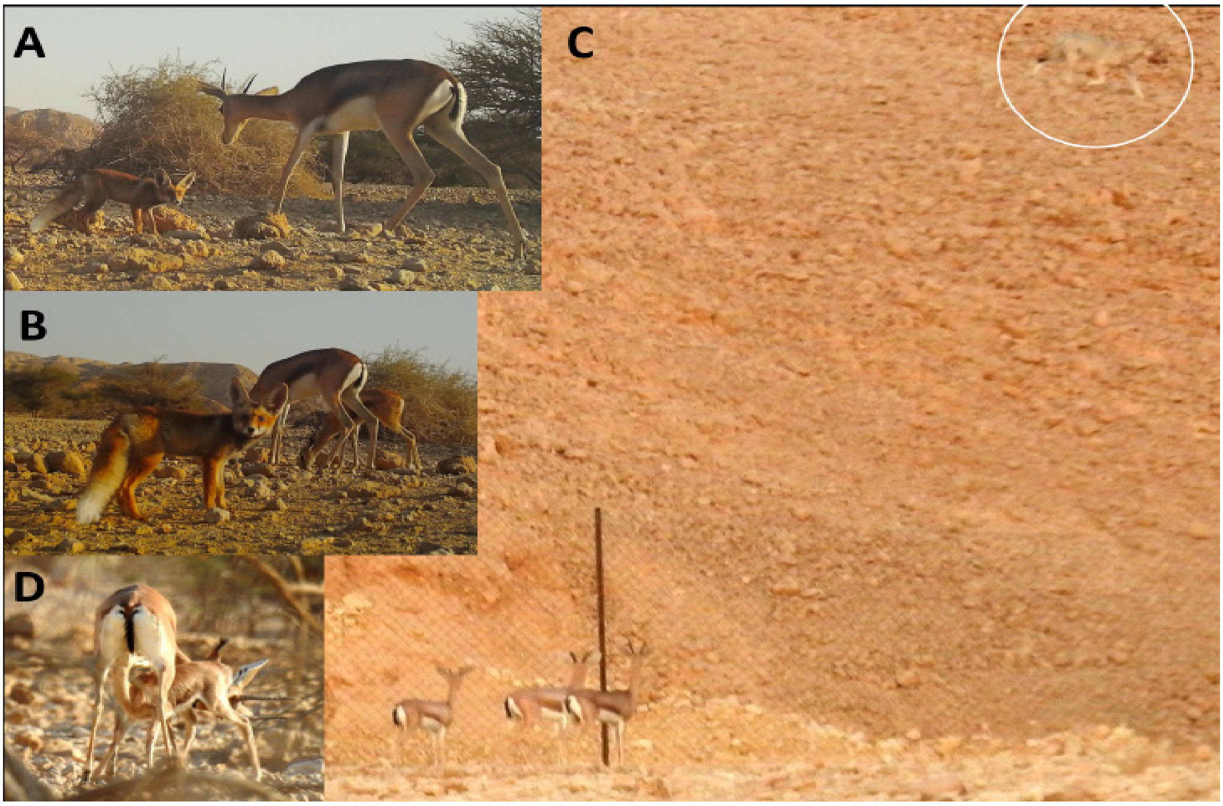

Figure 9: Red fox (Vulpes vulpes) is not considered a predator of Arabian gazelles: after initial confrontation of the fox by the female **(A)**, the behaviour of mother and fawn is not influenced by the presence of the fox **(B)**. The major predator of Arabian and dorcas gazelles in the Arava Valley are wolves (Canis lupus), repeatedly trying to enter the Arabian gazelle enclosure of the Yotvata NR to prey on fawns and adults of both gazelle species **(C)**. The most devastating threat to the G. arabica population in Israel is the exceptionally low fawn survival. To reduce the detectability of fawns by wolves, mothers remove and consume excretions whilst nursing the fawn **(D)**.

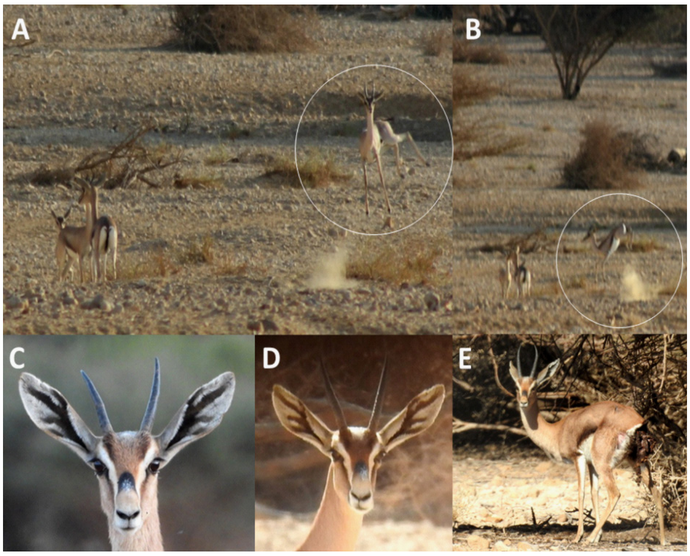

Figure 10: Play behaviour such as purposelessly jumping into the air, lifting all four feet off the ground simultaneously is predominantly performed by fawns and subadults **(A,B)**. First signs of low genetic diversity within the Israelian G. arabica population (inbreeding) include white nose spots **(C,D)** and stillbirths **(E)**. Interestingly, similar observations were made in a small, isolated (and probably inbred) population of Farasan gazelles (G. arabica farasani) persisting on Zifaf Island, which consistently exhibit a pale centre to a dark nose-spot [64].

Figure 11: Browsing on hind legs as described for many gazelle species, including Arabian gazelles on the Farasan Islands (G. arabica farasani; [65]) might be interpreted as a strategy to avoid competition with sympatric dorcas gazelles **(A,B)**. A mixed group of Arabian and dorcas gazelles in the G. arabica enclosure of the Yotvata NR **(C)**. Analysis of wolf scat revealed that around 50% of the diet composed of human subsidies such as agricultural produce (e.g. dates; **D**).

Based on preliminary research results obtained since 1984 and recommendations given in [43,67], the INPA decided in 1987 to expel the general public from the western part of the Yotvata NR. The improved protection status and regular ranger patrols further facilitated the population increase of the early 1980s (Figure 2) and allowed for some initial studies on the reproductive biology, life history and fawn survival [44]. The early 1990s were characterised by a steep decline in population size, prompting the INPA to initiate the 'Conservation Program for the gazelle Gazella gazella acacia', a first attempt to define future conservation goals for the species in Israel [38]. In an excerpt of that report, [46] speculated that the population suffers from inbreeding (first signs include stillbirths and white nose spots, Figure 10C-E), possibly lowering females' productivity and increasing the fawn mortality.

Despite Shalmon's study [67] on the content of wolf scats, monitoring results suggested a strong impact of predation on the gazelle population. The report emphasised that the increase of predator numbers in the southern Negev (mainly wolf, Canis lupus and stray dogs) has substantially contributed to the decline of the gazelle population and that a control program should be implemented. Shalmon [38,46] was the first to propose a conservation strategy for G. arabica, including three key aspects, i.e., in situ conservation of gazelles and their habitat in the Yotvata NR, the establishment of an ex situ breeding program, and the subsequent release of gazelles at potential reintroduction sites, located within the original range and comprising of suitable habitat (Figure 1). In 1993, [47] reported no progress regarding the captive breeding program, requesting the scientific community for advice and the INPA to urgently act. Seven years later, the INPA had eventually refused to establish a captive breeding population because using mass-capture boma or tranquilisation-as suggested by Shalmon [46]-would have put the life of the gazelles at risk [49]. Indeed, this was a wise decision since in 1996 the population size reached, with 10 individuals, the lowest value ever [48]. Instead the INPA initiated an irrigation program to improve habitat quality and food availability by watering a patch of Vachellia trees and by providing artificial water sources and supplementary food (Alfalfa, Medicago sativa; [49]). Back then, the issue of predator control was broached again calling for control measures such as wolf-culling and limiting the access of carnivores to human waste and agriculture surplus. Blank [50] proposed that the low population level was due to the high numbers of carnivores that had recovered from the rabies outbreak during the late 1990s. Moreover, a possible hybridisation with dorcas gazelles was discussed [49] as a reason for the low fawn survival reported by Shalmon [46], and the construction of a fence was debated as a valuable option to protect the gazelle population from predation [50].

In 2005, the INPA initiated a predator-culling program (from 2005 to 2008, INPA rangers killed 36 wolves in the area; [37]) and the construction of a fenced enclosure (3.5 km^2) in the prime habitat of the remaining eleven gazelles. By the time the fence was completed in 2006, the population had increased to 15 individuals, but in his article 'Sunset of the Acacia gazelle', Blank [2] predicted the demise of the G. arabica population under confinement. Furthermore, the author proposed four major causes for the grim conservation state: i) vegetation changes due to lowered ground-water table, ii) road kills on the Arava highway, iii) predation (mainly by wolves) and iv) genetic problems (i.e., inbreeding). After the enclosure was in place, wolves were excluded and the G. arabica population steeply increased to 55 individuals by 2012, the highest count since 1977 (Figure 2). This development gave reason for hope until severe flash floods in winter 2012/13 destroyed the fence and allowed wolves to enter the enclosure. Within a few months, until the fence was rebuilt, 43 gazelles were killed and the population plumped back to 12 individuals [28]. Since 2010, the INPA has implemented bi-annual drive counts inside the enclosure (one in winter, another one in summer), which was increased to four counts per year in 2017 (two counts on consecutive days in summer, two in winter; [68]).

Recent research

The current conservation status of Arabian gazelles in Israel was described in the 'Strategic Plan for the Conservation of *Gazella arabica*' [68]. The plan critically reviewed the conservation measures put in place since monitoring began and summarised and discussed possible ways out of the crisis. In recent years, some empirical studies have provided scientific evidence, modifying unsubstantiated claims regarding the causes of the described conservation failure. Barocas et al. [69] found that wolves in arid environments indeed depend on human waste and agriculture surplus and that this was the reason for their concentration near human settlements in the Negev. The population size of wolves in the southern Negev (namely Eilat district) was estimated to be 33 to 55 individuals, similar to other arid regions in Israel [70]. The authors rejected claims that predator populations are un-naturally high in the area and called for more detailed studies on the population dynamics of gazelles in the Negev, especially in relation to inbreeding, before instigating any further predator control programmes. This was realized by [3], who revealed that the genetic diversity of G. arabica in Israel-based on mitochondrial and nuclear markers-was evidently lower than that of other Arabian gazelles, indicating a severely inbred population. Another study investigated whether the Arabian gazelles encountered substantial browsing competition by sympatric dorcas gazelles. Breslau et al. [66] compared the browsing line of Vachellia trees inside the fenced enclosure to that created by dorcas gazelles in areas where no Arabian gazelles occur (i.e., Evrona, Hai-Bar Wildlife Reserve, Shezaf NR, and Wadi Shita; Figure 1). The authors discovered a significantly higher browsing line in the fenced enclosure of the Yotvata NR than in the other areas, suggesting that Arabian gazelles indeed experience competition from dorcas gazelles. Since 2008, more than 350 dorcas gazelles were therefore expelled from the enclosure and released into the unfenced part of the Yotvata NR (Table 1). Eventually, [28] related the development of the G. arabica population over a period of 22 years to the appearance of wolves in the Yotvata NR using time series analysis. The study unrevealed not only a similar predation pressure on Arabian and dorcas gazelles, but also two periodic population cycles, one lasting about three years, the second one about six years. Such fluctuating population size patterns (Figure 2) are indicative for coupled predator-prey cycles and thus confirmed the impact predation pressure had on both gazelle species in recent decades.

Table 1: Count results of male, female and juvenile dorcas gazelles in the G. arabica enclosure from 2006 to 2020. The fawn/female ratio is given as a measure for recruitment, and the number of expelled dorcas gazelles from the G. arabica enclosure into the unfenced parts of the Yotvata NR is provided to explaining the decreasing total in certain years. Until 2010, dorcas gazelles appeared to have not suffered from food shortage, but during the last decade the female-fawn ratio decreased notably.

Year	Male	Female	Fawn	Total	Fawn/female ratio	Expelled to unfenced NR
2006	12	45	25	82	0.56	0
2007	25	48	56	129	1.17	0
2008	43	79	59	181	0.75	94
2009	36	45	20	101	0.44	8
2010	43	44	28	115	0.64	36
2011	24	46	25	95	0.43	4
2012	44	78	28	150	0.34	20
2013	39	57	13	109	0.22	0
2014	45	73	11	129	0.15	0
2015	56	87	13	156	0.15	19
2016	41	74	6	121	0.08	38
2017	28	75	9	112	0.12	24
2018	15	47	2	64	0.04	66
2019	9	25	11	45	0.44	39
2020	9	20	1	30	0.05	0

Conservation actions and future objectives

In summary, the decline of the G. arabica population in Israel was essentially attributed to i) low fawn survival, ii) high predation pressure on adults and fawns, iii) low genetic diversity (inbreeding), or more recently to iv) climate change. In the following we want to discuss these threats in detail and critically reflect on previous and future conservation activities to reverse the trend and work towards a stable and resilient population.

Fawn survival

The most devastating threat to the G. arabica population in Israel is the exceptionally low fawn survival [28,38,44,46,71] (Table 2). Females reach sexual maturity at the age of 1-1.5 years and after a gestation period of six months, first parturition occurs at an average age of 22.4 (± 3.6) months (N = 9), usually yielding a single fawn. Most mothers come into post-partum oestrus within one month after birth (N = 25; [38]). On average, every female gives birth to 1.14 ± 0.27 fawns per year [38, 43, 46]. Most fawns are born in spring and to a lesser extend in autumn, but births can occur throughout the year [38,71]. The average male/female ratio at birth was approximately 1.0, suggesting that male and female births were close to parity. Fawns lying out for 6.12 ± 1.63 weeks (N = 25) and are weaned after 100.4 ± 29.4 days (N = 29; [43]). Compared to other desert-adapted gazelles (G. dorcas: 1-2 weeks, [72]; G. subgutturosa: 4-6 days, [73]; G. marica: One week, [74]; G. arabica (Arabian populations): Two weeks, [61]), this is a comparatively long lying-out period that might be responsible for the extremely low fawn survival rate of 0.34 ± 0.13 to the age of five months (N = 88; [43,71]; Table 2). This long lying-out phase makes fawns particularly susceptible to carnivore predation, allowing eventually only 4% of female offspring to reach sexual maturity [38,71]. Thus, numbers of young females recruited each year to the adult population continued to decline since records started in 1984 [38].

Table 2: Number of females and number of births in the respective year, number of fawns surviving to the age of 0 to ≥6 months and the percentage survival of G. arabica fawns in the Yotvata NR from 1986 to 1994 [38]. For details on fawn survival after 1994 see [28].

Year	Number of females	Number of births	0	1	2	3	4	5	≥6	Percentage survival
1986	23	12		3		2			7	58
1987	26	23		4	2	3	1		13	57
1988	25	28	1	9	5	2	1		10	36
1989	28	22	4	7	2	4	1		4	18
1990	21	27	15	5	1	3			3	11
1991	18	17	7	5	2		1		2	12
1992	15	16	7		4	2	2		1	6
1993	13	17	9	3	1	1			3	18
1994	9	17	4	5	2	1	1	1	3	18

It was argued that the poor food availability during months after weaning (> 3 months of age; [18]) is responsible for the low survival rates. During the hot and dry summer months, only a few green Vachellia leaves are left within the reach of young gazelles. This is mainly due to the high degree of competition with dorcas gazelles (especially in the last decade; [66]), and thus G. arabica fawns depend mainly on fallen pods and flowers of Vachellia. Feeding on fallen food items, exposes juveniles with low immune defence to the Gastro-Intestinal Tract (GIT) parasite contamination of the soil. Given that the enclosure is fenced since 2006, faeces (and therefore parasite eggs) of both gazelle species have accumulated inside the small enclosure, probably leading to an abnormally high contamination with GIT parasites [75,76]. Consequently, the high tannin content in the resin of Vachellia trees [77] and its antimicrobial activity [60] may be the reason for the high degree of resin browsing observed in Arabian gazelles (Figure 5). Interestingly, resin and bark browsing were increasingly observed since July 2020, after a period of 35 years without any observation despite intense monitoring.

It is imperative to closely investigate at what age survival rates decrease and during what developmental stage most fawns are lost. Moreover, parental attributes like the mother's experience (age at parturition) or offspring related attributes such as the sex or weight at birth need to be considered. Preliminary results suggest that parental and offspring-related attributes played no role, but the weather conditions after birth-and depending on this the food availability-are vital to the survival of fawns [71]. The study revealed that out of 97 fawns, 92 survived to weaning age (3 months), 73 to the age at which males leave their mothers (5 months) and only seven fawns survived to the age of reproductive maturity (12 months).

To improve fawn survival, juvenile gazelles need to be protected from predator attacks, insinuating that the fence surrounding the gazelle enclosure should remain in place and its fortification should be considered an essential management tool [68]. Only fenced areas such as the Mahazat as-Sayd Protected Area in western Saudi Arabia allow the efficient protection of Arabian gazelles, since they prevent wildlife from illegal pursuit, to some degree from carnivore predation and from competition with domestic livestock [37,78,79]. Since 1970, livestock is completely excluded from the area of the Yotvata NR, but competition with sympatric dorcas gazelles ought to be further reduced [66,68]. The most suitable way to achieve this management goal is the removal of dorcas gazelles from the enclosure using a drive-in boma. Hereby, one or two vehicles separate the dorcas gazelles from Arabian gazelles and drive them into a funnel that leads into a narrow end section, from where the animal(s) can be released into the surrounding habitat of the Yotvata NR [38]. The ambitious aim is to expel at least 40 dorcas gazelles per year [68], i.e. a number that exceeds the recruitment rate of dorcas gazelles, i.e. 0.24 fawns per female per year [80].

Carnivore predation

Since the Arabian leopard (Panthera pardus nimr) is largely extirpated in Israel (Shalmon unpubl. data) and caracal (Caracal caracal) and striped hyaena (Hyaena hyaena) are rare in the southern Arava Valley, canines (mainly wolves and stray dogs) are considered the main predators of gazelles and are accountable for their decline [37,81-84]. This equally applies to mountain gazelle populations from Upper and Lower Galilee or the Golan Heights [85-87], to dorcas gazelles in the Negev Desert [41,69,72,88], and certainly to the Arabian gazelle population in the Arava Valley [2,28,38,46,49,50]. The behaviour of adult and juvenile gazelles, however, indicates that red foxes (Vulpes vulpes) do not prey on gazelles (Figure 9A,B). In recent decades, densities of canine predators have markedly increased in Israel, especially in areas that were previously uninhabited [86,89,90]. Human garbage, undisposed carcasses of domestic livestock and unused or dropped agricultural products were held accountable for this increase [67,69,85,86,88,90]. Despite strong indications that wolves control the gazelle population, some studies disagreed, stating that only a small proportion of investigated wolf scats contained gazelle components [67] and that there is a lack of evidence that increased canine predation is owed to abnormally high predator densities [69,70]. Surplus killing (sensu [91]) could be one possible explanation for the discrepancy between high gazelle mortalities and a comparatively small proportion of gazelle items in wolf scats [28]. Surplus killing describes a phenomenon whereby well-saturated predators kill more prey than needed to survive or successfully reproduce, specifically under conditions where prey is abundant and easily accessible [91].

Since the early 1990s wolves were suspected to have a major impact on the G. arabica population in the Yotvata NR [2,38,46,49,50,92,93], but only recently [28] provided some evidence that wolf predation indeed has a significant effect on the gazelle population. The study revealed a similar predation pressure on both gazelle species, but also two periodic population cycles, indicating a fluctuating population size pattern such as that known from other coupled predator-prey cycles. This predator-prey cycle was suggested to have a repeated time lack of three and six years, whereby the three years' cycle represents high wolf densities and the six years' cycle high gazelle densities or vice versa. This pattern matches a bottom-up control of wolves through prey availability when gazelle abundance is high, and a top-down control of gazelles by wolves when wolf abundance is high.

Given the above experiences, observations, and research findings, it is obvious that not only fawns suffer from wolf predation but also adult gazelles [92]. Thus, four predator control measures were suggested and implemented since wolf predation became imminent in the late 1980s: i) fencing, ii) culling iii) human garbage and agricultural surplus control IV) captive breeding.

Fencing: Following suggestions by [2,49,50], the fence encompassing the G. arabica enclosure has a length of 7.21 km, a height of 2 m and its lower part is embedded into the soil. On the outside, the fence is surrounded by an electric wire-fence to prevent wolves from climbing the enclosure [37] (Figure 9C). Since July 2006, the gazelle population is effectively protected within the 3.5 km^2 area, but before the fence was erected and during periods the fence was destroyed by flash floods, the gazelle population encountered catastrophic losses due to wolf predation [28]. The protection of gazelles by the fence is therefore imperative for their survival-without this protection the population would be most probably extinct by today. However, at this point it should be stressed that the conservation of the gazelle population, especially the maintenance of the fence, requires tremendous funds to be allocated by the INPA and the Israeli government, raising the principle question whether it is proportionate for the INPA to invest these considerable resources into a small residual population, while at the same time neglecting the protection of other species or habitats (see discussion below).

Table 3: Date, location, and number of wolf sightings (including wolf tracks) encountered in the southern Arava Valley (i.e. between Paran and Eilat) from 1985 to 2005. Yotvata NR-west refers to that part of the Yotvata NR located west of the Eilat Highway and which was fenced in 2006 as the G. arabica enclosure.

Date	Location	Number	Remarks
1985	north of Yotvata NR	3	Juvenile wolf tried unsuccessfully to chase a herd of G. arabica
Feb 1985	Nahal Racham	2	At feeding site of Torgos tracheliotus*
Jun 1986	Nahal Racham	1	At feeding site of Torgos tracheliotus*
Dec 1991	Yotvata NR-west	2	2 wolves chasing a gazelle
total 1995	Yotvata NR-west	3	1 observation
total 1996	Yotvata NR-west	7	5 observations
total 1997	Yotvata NR-west	4	4 observations
total 1998	Yotvata NR-west	4	3 observations
total 1999	Yotvata NR-west	8	5 observations
Feb 2000	Yotvata NR	?	Tracks around carcass of G. dorcas
21 Feb 2000	Yotvata NR-west	2	Female wolf hunted a male G. dorcas, male later joined the carcass
through 2000	Yotvata NR-west	2	Same couple as above, 2-3 times a week
Oct 2000	Yotvata NR	2	Tracks of adult and juvenile
total 2000	Yotvata NR-west	26	16 observations
2001	Yotvata NR-west	1	Single individual hunting G. dorcas (2 adult males, 2 fawns two months old)
2001	Yotvata NR-west	1	Single individual hunting herd of G. arabica
2001	Yotvata Hai-Bar WR	?	3 predation events: G. dorcas (male & fawn), G. arabica (fawn)
total 2001	Yotvata NR-west	57	33 observations
total 2002	Yotvata NR-west	65	28 observations
total 2003	Yotvata NR-west	65	38 observations
total 2004	Yotvata NR-west	37	23 observations
total 2005	Yotvata NR-west	28	17 observations

Culling and rabies: Since the early rabies outbreaks in Israel during the 1950s, three waves of rabies hit the Arava Valley, decimating the number of canine predators significantly. A rather mild wave occurred from October 1988 to July 1989; a severe wave from May 1997 to May 1998 and a local outbreak in the southern Arava from August 2003 to February 2004 [92]. Rabies outbreaks usually occur when canine densities are high and therefore prey densities are low. This was the case prior to those outbreaks causing high canine mortalities and therefore relaxing the predation pressure on the gazelle population. To discontinue the spread of rabies, the INPA decided to cull 60 red foxes between July and October 1989, 14 wolves during the second outbreak in 1997 and one wolf, ten foxes and three jackals in 2003/04 [93]. During the epidemics and after the culling of canine predators, fawn survival increased in the reserve to 69% in 1999, but decreased again to 0-22% between 2003 and 2005 [28] (fawn survival before 1995: Table 2, wolf encounter rates from 1985 to 2008: Table 3). In 2005, the INPA implemented another predator-culling program in the southern Arava Valley, killing 36 wolves between 2005 and 2008 [28, 37]. Reducing canine predators in the area was-and still is-considered essential to protect the gazelle population, but also to prevent people, their pets and livestock from contracting rabies [37]. The decline in the number of wolves did not only benefit the survivorship of G. arabica fawns, but also increased the dorcas gazelle population, reaching 240 individuals by 2013 [28,92,93]. However, culling predators is a very controversial and emotional issue since both, the predator and the prey are species threatened by extinction in Israel [69,70]. These conflicting conservation interests are problematic since preserving one species, inevitably prompts negative effects on the conservation of the other. To control the canine predator population in the southern Negev, it is therefore recommended to first apply less invasive measure such as fencing the gazelle population or limiting the access of canines to human waste and agriculture surplus (sanitation) before applying more rigorous methods such as culling [68-70]. Currently, about 30 to 50 wolves inhabit the southern Arava Valley (Eilat District; [70]).

Management of human subsidies: Human activities in the Yotvata area are dominated by small settlements, agricultural infrastructure including crop fields and date orchards, military bases, and garbage dumps [94]. Human garbage, undisposed carcasses of domestic livestock and unused or dropped agricultural products (mainly dates, Phoenix dactylifera) were held accountable for the increase of canine predator populations in the area [67,69,85,86,88,90]. For example, the date palm production of the Kibbutz Samar alone yields approximately 60,000 kg of ripe fruits fallen to the ground during each harvest (Figure 11D). Barocas et al. [69] concluded that Negev wolves predominantly rely on these and other human subsidies, leading to a thriving wolf population and inevitably to an increased predation risk to their prey species. Analysis of 466 wolf scats confirmed that the major dietary components of wolves in the southern Arava Valley were carrion of domestic livestock (found in 62.5% of scats), agricultural produce (in 51.4%) or garbage and other human discard (in 37.2%; [67]). Only 1.1% of the investigated wolf scats contained gazelle hairs (including G. dorcas and G. arabica), some of which were probably from carcasses [67,88].

A general, negative impact of anthropogenic food resources on predators was studied by [94,95] and in Israel several studies focused on the consequences of reducing anthropogenic food resources, making suggestions on how to best achieve this important conservation target [90,98-101]. Specific proposals to decrease the wolf populations in the Yotvata area include the reduction of surplus food through management of garbage dumps, the construction of fences, and to improve sanitation, explicitly the appropriate disposal (burying or burning) of live stock carcasses [38,90]. Moreover, unused agricultural produce such as dates or crops need to be used as fodder for livestock or buried for rapid decomposition. However, these management tools require the cooperation of local communities around Yotvata and in the southern Negev, which proofs rather difficult due to the conflicting interests of various stakeholders involved (i.e., farmers, local authorities, military, private property owners, etc.).

Captive breeding: Between 1965 and 1988, several attempts were undertaken by the INPA to capture lying-out fawns, raise them by hand and establish a breeding nucleus in captivity from which gazelles could be released to reinforce the wild population. To obtain gazelle fawns, rangers followed pregnant females to collect their new-borns once left alone by the mother. Fawns were then given to several institutions and private persons to be hand-raised but most fawns died within a short period for different reasons (Table 4). These experiences clearly illustrate how difficult-if not impossible-it is to hand-raise wild born gazelle fawns.

Table 4: Efforts to establish a captive breeding stock of G. arabica based on captured adults or hand-raised fawns obtained from the wild (see main text). Locations and institutions with captive breeding attempts: Canadian Centre for Ecological Zoology, Tel-Aviv University (TAU), Eilat Zoological Garden (EZG), Yotvata-Hai-Bar Nature Reserve (HB), fenced enclosure on the premises of the Zuf family, Ein Yahav (EY), fenced enclosure on the premises of G. Ilani, Merkaz Sapir (GI). References: (1) G. Ilani, pers. comm.; (2) H. Mendelssohn, pers. comm.; (3) R. Malka, pers. comm.

Year	Age at capture	Sex	Location	Results
1965	fawn	M	TAU	Died at age of 2 weeks (1)
1966	fawn	M	EZG TAU	Sent to TAU when 3 years old (1) Died in TAU at the age of 9 years, no offspring as no female available (mated with G. gazella female producing several fertile offspring)
1974	adult	M F	HB	One fawn (F) born in captivity (May 1974), later released with offspring into the fenced part of the Yotvata NR (3)
1975	adult	M F	HB	Two fawns born in captivity (April 1976, May 1977), later released with offspring into the fenced part of the Yotvata Hai-Bar WR (3)
1982	fawn	M	EY	Died at the age of 2-3 years from an injury caused by another male (1)
1982	fawn	M	EY	Died at the age of 2-3 years by trauma (scared by dogs jumped into the fence and broke his neck (1)
1983	fawn	F	GI	Died at the age of 2 weeks from intestinal blockage (1)
1988	fawn	F	HB	Died at the age of 2 weeks from a barley seed that perforated the gut (2)

In the early 1990s, Shalmon [38,46] suggested to establish a captive breeding and reintroduction program that aimed to quickly enlarge the population by establishing a breeding nucleus in the nearby Hai-Bar WR (a 12 km^2 breeding and acclimatisation facility located within the Yotvata NR). Shalmon [38] proposed two to three breeding pens each containing three to six females and one adult male. Additionally, a bachelor group should be established to contain young and sub-adult males. Each pen ought to be equipped with water, surplus food, mineral licks and a shelter following descriptions and husbandry recommendations provided by [102]. Furthermore, it was suggested to establish a studbook for G. arabica acaciae, monitoring the pedigree of all captive-and if possible-wild gazelles to avoid inbreeding and maintain genetic diversity. Breeding males should be exchanged between breeding pens and regularly replaced by maturing males from the bachelor group or by additional wild captures. Subsequently, the progeny should be transferred into an acclimatisation pen within the boundaries of the Hai-Bar WR to form a cohesive social unit as a potential release population. This would prepare the animals for reintroduction by soft-release and ease subsequent post-release monitoring. Potential reintroduction sites in the Arava Valley include the gazelle enclosure in the Yotvata NR, the Hanhalim Hagdolim NR, the Evrona NR and the wadis of the Eastern Negev [46] (Figure 1; Table 5).

Table 5: Name, size, location, and description of potential re-introduction sites for G. arabica in Israel.

Name	Size	Location	Description	Other ungulates
Evrona & Eilat mountains NRs	40 km^2	29°34'30.54"N 34°55'19.16"E, Figure 1, A	This area has a good population of both Vachellia raddiana and V. tortilis. The area is disturbed by human activities such as industrial plants, the new Eilat airport, a railway, roads, solar panel plants, agriculture, and tourism. These disturbances are expected to increase in the future and the suitability as a potential reintroduction area is therefore ranked as only third-class.	Until 1983 the area was populated by Arabian gazelles and still harbours a viable population of about 200 dorcas gazelles.
Arabian gazelle enclosure within the Yotvata NR	20 km^2	29°52'44.07"N 35° 2'23.08"E Figure 1, B	The area is fenced harbouring the remaining population of Arabian gazelle (G. arabica) in Israel. The enclosure comprises the densest Vachellia grove in Israel, representing ideal habitat for Arabian gazelles. The area is confined by cliffs to the west, by Kibbutz Samar and date plantations to the south, the Eilat Highway to the east and Kibbutz Yotvata to the north. The area can sustain a breeding nucleus of Arabian gazelles, but not a viable population. Due to its suitable habitat, this area is ranked best among potential reintroduction sites in case the existing population could vanish in the future.	A population of about 35 dorcas gazelles.
Mazok Hazinim and Machteshim-en Yahav NR	140 km^2	30°43'14.17"N 35°12'37.63"E Figure 1, D	The area is located in the eastern Negev and includes wadies of the northern Arava catchment. The area is rich in Vachellia raddiana and V. tortilis. However, large parts of the habitat were damaged by intensive camel and goat browsing. In the past, the area was probably home for a population of Arabian gazelles, suggesting that habitat and climate are suitable for a potential reintroduction. Due to being used as a target and training area for the Israel Defence Forces and the construction of a new railway track, the area is only ranked second among potential reintroduction sites.	The area harbours a small population of dorcas gazelles.
Hanhalim Hagdolim & Kezev-Hayun NRs	300 km^2	30°15'20.72"N 34°57'47.40"E Figure 1, C	The area has a moderate density of Vachellia raddiana and V. phachyceras trees in several large wadies. Most of the area serves as a target and training area for the Israel Defense Forces. The area comprises a high plateau with ambient temperatures lower than in the Arava Valley. In the past, single Arabian gazelles were observed at the fringes of this plateau. Due to its remoteness and moderately suitable habitat, this area is ranked second among potential reintroduction sites.	The two reserves harbor a population of about 300 dorcas gazelles, and few dozens of Arabian oryx (Oryx leucoryx).

Given the despairing situation in recent years, at times containing only eleven individuals in the fenced enclosure, one could argue that this is already a captive population and that management could be intensified and more efficient in small standardised breeding pens [102]. However, the INPA eventually refrained from establishing a captive breeding nucleus due to the high risk involved during capture or immobilisation [47]. Potential capturing methods would include immobilisation using Immobilon® (M99), a drive-in boma, nets or dazzling at night [38]. Immobilization with M99 (which was effective in G. gazella; [103]) would require a veterinarian to enter the enclosure by vehicle and to get as close as 20 m to discharge the syringe safely. Since flight distances of gazelles are much longer (50-70 m)-even at night-this method was considered inappropriate. Immobilization, like any other method of capture, is extremely invasive and can cause shock, trauma or even mortalities. Given that would happen to only a small percentage of targeted animals, this would be extremely undesirable in such a small population.

Low genetic diversity (inbreeding)

At least since monitoring started, the G. arabica population in Israel is small and isolated from other populations in Arabia. Small populations are prone to inbreeding which has deleterious effects on reproduction (male semen quality and female fertility) and fawn survival (i.e., inbreeding depression; [104-106]). Such negative effects are due to a decreased heterozygosis that occurs when related individuals repeatedly mate [107,108]. Since fawning in the Yotvata population is prolific but fawn survival rates are low, the conservation program for this isolated relict population was also based on the hypothesis that low fawn survival could be due to a severe inbreeding depression [2,38,46]. This hypothesis was later confirmed by [3], who found that genetic diversity was markedly lower than that of other Arabian gazelles and that such a pattern is characteristic of an isolated and severely bottlenecked population. This result was based on both, mitochondrial and nuclear DNA markers and thus strongly supporting the suspected inbreeding depression [3].

Inbreeding has been described for many captive gazelle populations, including G. dorcas, G. cuvieri, Nanger dama and G. spekei [109-111]. Experiences from these populations showed that fawns produced by inborn mothers usually die within six months after births, most of them during the first four weeks [104,109-112]. In the Yotvata population, most juveniles died after the age of three months, suggesting that deleterious effects of inbreeding are rather unlikely to be the cause for the low fawn survival. However, years with lower births rates (Table 2) could be indicative for periods in which most pregnancies were stillborn or abortions [38] (Figure 10E).

Inbreeding in small, isolated populations typically increases the extinction risk [106]. Restoring the gene flow between isolated populations or introducing genes from related population can reverse the inbreeding depression. This process is known as 'outbreeding' and should be considered a major management tool to increase the genetic diversity of G. arabica in Israel. Geographically, the nearest known population occurred in the late 1990s near the Saudi town of Haql at the Gulf of Aqaba (south of Wadi Khulagb, N28 56.950, E34 50.654; [20,113]), followed by the Harrat Uwayrid population in the Hejaz Mountains of north-western Saudi Arabia (today located in the newly established Sharaan Nature Reserve; [7,114]). Genetically, the nearest known population occurs on the Farasan Islands in the southern Red Sea [3]. This population was identified as a genetic reservoir for potential reintroductions on the Arabian Peninsula in case mainland populations vanish or need to be reinforced [27]. Despite political constraints, the most suitable way to overcome the inbreeding depression would be the reinforcement of the existing population with individuals from Saudi Arabia. Arabian gazelles were bred for more than 30 years in the scientific collections of Prince Saud al-Faisal Wildlife Research Centre (previously National Wildlife Research Centre, NWRC) in Taif and the King Khalid Wildlife Research Centre (KKWRC) in Thumamah, near Riyadh, whose captive stock predominantly originated from western Saudi Arabia [20]. Furthermore, the Al Wabra Wildlife Preservation (AWWP) in Qatar breeds a good number of Arabian gazelles, but most of which originated from the eastern parts of the species range (UAE; G. arabica 'cora') and may thus proof genetically too distant, potentially instigating an outbreeding depression (sensu [106]).

Climate change

Comparing the mean annual rainfall in the southern Aravah Valley from 1951 to 1993, to that measured from 1993 to 2009, suggests a decreasing volume of approximately 0.29 mm precipitation per year [115]. Moreover, mean temperatures in Eilat have increased from 1995 to 2009, relative to the period from 1981 to 2000. Daily maximum temperatures for January and July measured in Eilat have increased from 20.8°C to 21.3°C and from 39.9°C to 40.4°C, respectively [116].

In their study on the conservation management of wolves in the Negev Desert, Cohen et al. [70] requested a detailed study on the population dynamics of gazelles, especially with regard to climate change, before initiating any further predator control mechanisms in the area. Using time series analysis of historic climate data and wolf encounter rates, [28] revealed that climate has indeed a moderate, negative effect on fawn survival while wolf predation appeared to significantly influence the population dynamics of Arabian gazelles.

Other authors [41,117] also argued that increasing temperatures and decreasing precipitation are responsible for the constant population decline. Given that the Arava population occurs in a hyper-arid depression at the northern periphery of the species' distribution, it is expected to be more vulnerable to climate change than in the centre of its distribution (i.e. on the Arabian Peninsula). The opposite is more likely to be the case, i.e. an increasingly warmer and drier climate, as it is observed on the Arabian Peninsula, would not harm the population but rather benefit it. Instead it should be argued that a colder and more humid climate as known from the Mediterranean areas of Israel would negatively affect the population. Given that G. arabica was successfully (re)introduced into the hyper-arid climate of the Uruq Bani Ma'arid Protected Area in Saudi Arabia [6,118], the species seems to be well adapted to hyper-arid desert conditions. Once released into the wild, the population size increased rapidly, making it doubtful that the hot and dry climate of the Arava Valley negatively affects the gazelle population to the degree of local extinction. This hypothesis was partially supported by the conclusion that functional groups of desert-adapted vertebrates with high sensitivity and adaptive capacity (e.g. viviparous, endotherm, diurnal herbivores) are less vulnerable to climate change than other groups [119]. This functional group comprises all larger desert herbivores, including Arabian gazelles.

Conclusions

In summary, vital reasons for supporting the continued conservation of G. arabica in Israel include: i) maintaining the species' genetic diversity, i.e. to enable and facilitate high levels of intra-specific heterogeneity across all populations [37]; ii) the Arava population could function as a reservoir for reintroduction or captive breeding programmes in case other populations of G. arabica (e.g. on the Arabian Peninsula) face local extinction due to hunting, life-capture or competition with domestic livestock [68]; iii) to maintain or restore the ecological balance and functional diversity of the desert ecosystem in the southern Negev [120], and iv) the study of a fenced population in a semi-natural environment will enable scientists to identify processes and solutions for other small ungulate populations at the brink of extinction [68]. However, half a century effort to preserve the Arabian gazelle population in the Arava Valley were of only limited success, and as shown above, the population continues to face catastrophic events such as that in May 2020. Hence, it needs to be questioned whether 55 years of monitoring and conservation management have helped to improve the status of the population and whether results from above cited studies can help to define future incentives. What did we learn in 55 years?

Consequently, the question is what essential management actions can be recommended that have not been implemented previously or that were identified to be suitable to preserve the population? As proposed for many years, inbreeding is indeed weakening the genetic resilience of the population presumably leading to increased fawn mortality [3]. An outbreeding attempt would benefit the genetic diversity of the population and might result into increased fawn survival. Apparently, fawn survival seems to be also affected by the climatic conditions after parturition [28,71]. However, that does not necessarily mean that climate change has a negative impact on the overall population development (see discussion above). It rather seems that predation is the major driver for the turbulent population development of G. arabica in Israel and the high losses to fawns and adults [28].

Yom-Tov [37] highlighted that inbreeding and climate change are difficult to manage and thus the only way to protect the G. arabica populations from local extinction is a fence. Fences are suitable measures to prevent illegal hunting or predation but on the other hand they are undesirable for conservation. This is mainly because of the disruption of migration routes towards green pasture after localised rain events, preventing the gene flow between populations and therefore leading to the impoverishment of genetic diversity and inbreeding [121,122]. Since contact to neighbouring G. arabica population is interrupted at least since the British mandate for Palestine this is no longer a valid argument. Moreover, Arabian gazelles are sedentary and territorial, never forming large aggregations migrating over large distances. We therefore consider the fortification and continued maintenance of the fence, i.e. to prevent the population from being further diminished by wolves, the most imperative conservation measure that can be proposed at this time. Culling of predators must be the very last resort to achieve this objective.

The construction of the fence surrounding the G. arabica enclosure in the Yotvata NR required an investment of about one million New Israeli Shekel (NIS) raised by ARAVA Mines Ltd. and supported by a donation from the Jewish National Fund in the United Kingdom. Regular maintenance and repairs require consistent investments, especially after the catastrophic flash floods of October and November 2012, or in February 2013 that destroyed large parts the fence. At this point it should be stressed that the conservation of the gazelle population, especially the maintenance of the fence, requires tremendous funds to be raised by the INPA and the Israeli government. This raises a principle question: Is it proportionate for the INPA to invest these considerable resources into a small residual population while at the same time neglecting the protection of other species or habitats? This question was raised in a questionnaire to previous and current Head of Departments of the INPA as well as to scientists from the Israeli Academy that were involved or interested in the countries' nature conservation. Only 15 persons responded, of which all but one agreed that the INPA should continue to maintain the G. arabica enclosure as it is, knowing it might repeatedly collapse during future flash flood and consume further resources that could be otherwise invested into more urgent conservation projects (e.g. the re-establishment of vulture populations). Nevertheless, the question has no consent at the moment and remains highly disputed within the conservation community in Israel. Those who oppose the investment argue that the climate, and thus the habitat, has changed in the southern Arava Valley and that the decline of the gazelle population is part of this change. Indeed, the climate in the region has changed over recent decades, at the same time causing profound changes to the vegetation [115,123]. Those who support the continued conservation of the gazelle population emphasize that the present situation is due to severe human-induced habitat modifications, such as lowering the ground water table or facilitating the population growth of predators through increased food availability, and hence society has the responsibility to prevent the gazelle population from local extinction [37].

Second most important for the conservation of Arabian gazelles is the continued expelling of dorcas gazelles from the G. arabica enclosure into the unfenced parts of the Yotvata NR (Table 1). Since dorcas gazelles inside the enclosure produce at an annual rate of one fawn per adult female and have a fawn survival rate of 0.24 [80], it is envisaged to remove 40 individuals per year [68]. Another measure to reduce competition between the two gazelle species is the provision of artificial water sources and supplementary food (pellets). After an initial trial, providing Alfalfa (Medicago sativa) to the G. arabica population in 1999 [49], this management tool was reconsidered by INPA in 2017. Arabian gazelles (mainly females and fawns) accepted the supplementary food and the population size increased until the most recent wolf intrusion.

High competition for limited food resources between G. dorcas and G. arabica caused food shortage for the fawns of both species [66]. Until 2010, dorcas gazelles appeared to have not suffered from food shortage, but during the last decade the female-fawn ratio decreased significantly (Table 1). It is therefore recommended to initiate a detailed study on the ecology and foraging behavior of dorcas gazelles inside the G. arabica enclosure to better understand the interactions between the two gazelle species. This should involve traditional methods, such as assessing the foraging efficiency through direct observations (Acceptable Food Abundance, [124]), in combination with with advanced methods such as near-IR spectroscopy to analyze the nutritional quality of specific dietary components of both species [125].

It was further suggested by [38] to plant Vachellia trees (V. tortilis and V. raddiana) in two to three rows, west of and parallel to the Eilat highway. Those trees can supply extra food for the gazelles and can give some protection from harassment by pedestrians or disturbance from vehicles. Such a plantation already exists along a strip of 100 m parallel to the highway, but the trees were planted too close to each other, preventing them to attain their maximum size. Nevertheless, the plantation showed that planted Vachellia trees will survive and have enough water (at least to the west of the road). In areas where Vachellia trees already occurred naturally, no further trees should be planted. To estimate the carrying capacity of the existing Vachellia woodland it is recommended to establish the available canopy by using remote sensing indices such as the Normalized Difference Vegetation Index (NDVI) or the Normalized Difference Leaf Canopy Biomass (NDBleaf; [126]). However, gazelles feed predominantly on the lower parts of the canopy which are concealed when viewing from above, implying that the remotely sensed canopy might have ample food, but gazelles cannot reach it.

As outlined above, 'fresh blood' is needed to outbreed the population. To obtain gazelles from genetically similar populations is politically difficult since all are located in Saudi Arabia (e.g. King Khalid Wildlife Research Center or Farasan Islands). Nevertheless, it is recommended to involve a neutral facilitator who could get into contact with the Saudi Wildlife Authority to start negotiations on behalf of the INPA. It would be also advantageous to exactly determine the degree of inbreeding in the G. arabica population (inbreeding coefficient, [106]) and to possibly determine the genetic distance to populations in Saudi Arabia. To establish a captive breeding nucleus in the Hai-Bar WR, is not a suitable option at this point of time, mainly because of the low population size and the risks involved with capture or immobilization. Only if the population size reaches a level of more than 50 gazelles a capture of fawns and the establishment of a captive breeding stock should be considered.

We further recommend an in-depth research on parasitic infections, with focus on gastro-intestinal tract parasites such as helminths, trematodes, and protozoans of both gazelle species and across all age classes. Furthermore, statements on the risk of infection with GIT parasites at different foraging height levels should be determined and related to food quality (e.g.

the trade-off between feeding on highly nutritious, fallen pods and the risk of contracting an infection). Such results should be established across different seasons and related to genetic diversity and fawn survival.

Finally, it should be highlighted that the G. arabica population in Israel represents a national symbol already praised in the old testament. Because of their beauty, elegance and rich abundance, gazelles were-and still are-considered a biblical proverb to the land of Israel and could be therefore used as a flagship species for nature conservation in the southern Arava Valley. The Arabian gazelle, together with the doum palm (Hyphaene thebaica), two typical but rare organisms in the southern Arava region, mark the logo of the regional council of Elot District, governing the Southern Negev and could be further promoted to help protect this unique species. Moreover, as a flagship species for the region, Arabian gazelles could be used to augment tourism, making it a haunting event to visit the gazelle population, just like gorilla tracking in the mountains of the Albertine Rift Valley in central Africa.

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